Broadband Radio Communications in Subway Stations and Tunnels

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Abstract—**Broadband radio communication systems are very important for railway traffic control systems and passengers network services. Nowadays, even though 4G LTE (Long Term Evolution) has deployed for commercial use with excellent results in open areas, it is still lack of knowledge regarding to how such broadband signals propagate inside complex environments with many complex structures that affect propagation such as subway tunnels and stations. For this reason, the aim of the presented measurements in this paper is to model the response of the broadband channel at 1000 MHz and 2450 MHz in the subway environments. These measurements focus on three types of scenarios: subway stations, straight tunnels and a train effect the signal. The results provide detailed information about the propagation channel, which can be useful to develop a broadband propagation model for underground communication systems.**

I. Introduction

With the commercial 3GPP LTE is deployed globally and commercial market of 4G technology is opening and popularizing, broadband communication systems are expected to provide up to 20 MHz bandwidth with low latency [1]. Therefore, it permits new mobile communications capacities, which can afford more excellent communication way like high definition real time video. These technical advantages are very attractive for railway operators, to offer entertainment services and high speed data transmission to the passengers, and also to improve security and signalling system with video surveillance and other high quality services [2]. However, the reality is that most railway communication applications are still based on the widespread GSM-R (Global System for Mobile Communications - Railway) standard, which can only support narrowband signal transmissions [3] [4]. For future railway radio communication system, the drawback of GSM-R is that low data capacity can not meet the requirements like CCTV or other high capacity data transmission tasks. So the development of broadband radio communication system for railway is urgent and necessary, to provide high stability and quality of services, applications and added value services [5].

The main challenges related to the capabilities of broadband radio communications, and features to implement the required subway functionalities are: wide network coverage design process in high speed environments, QoS, access control mechanisms, performance of broadband signal handover mechanisms in high speed railway scenarios, spectrum deployment considerations and capabilities to meet the environment RAMS requirements [6]. For evaluate these challenges and test the impact of a new radio communications systems in subway environments, a broadband channel sounding system for TECRAIL project has been developed in Spain [7]. To evaluate the feasibility and performance of a broadband system on railway communications and signalling systems, A series of test trials has carried out in the subway of Madrid. The measurements are assigned to two groups of testing under three scenarios: subway stations, straight tunnels and a docked train at the station. The testing results refer to the evaluation of the effects on the radio signal from the subway station, tunnel and train passing, respectively. The remainder of the paper is organized as follows. In Section II, the whole test trail scheme is explained and channel sounder configuration is presented. Section III exhibits the measurements results and analysis it with radio signal propagation mechanism. And the conclusions is presented at the end.

II. Propagation Measurement Configurations

The subway system can be briefly divided to two regions: the underground station and connected tunnels. Based on this division, our measurements are assigned to two main groups called Test 1 and Test 2. In the first group, the testing is carried out on the platform of the subway station called Ciudad de los Ángeles (Line 3 of Metro de Madrid). In this set of scenarios, effects from the train body and subway station are evaluated. In the second group, measurements are made inside the tunnel that connect to the aforementioned station. In these cases, the effects from different position of tunnel are considered and characterized. Moreover, two common frequencies are applied in all cases to enhance the comparison: 1000 MHz and 2450 MHz. The results of the whole measurements can be expected to provide support for completely channel modeling in subway system.

Three models of antenna are chosen for the broadband measurement campaign: The HG908P works on 900 - 1000 MHz with 9 dBi gain and HG2414P on 2.4 - 2.5 GHz with

Transmitter		
Frequency range	500-6010 (4 bands)	MHz
Output power	42	dBm
IF bandwidth	1-100	MHz
Modulation	Pulse	47 ns
Receiver		
Frequency range	400-7000 (4 bands)	MHz
IF dual conversion	860/160	MHz
Noise figure	4	dB
IF bandwidth	5/10/20/100	MHz
Demodulation	Logarithmic detector	
Dynamic range	90	dB

TABLE I: Channel sounder configurations.

14 dBi gain. Both models are flat patch antennas used as transmitting and receiving antennas in Test 1 at 1000 MHz and 2450 MHz, respectively. In Test 2, the receiving antenna is replaced by R&S HL025 Log-Periodic antenna, which can works on 1 - 26.5 GHz and can be adsorbed on the train's tail (last car) as Fig.1 shows.

Fig. 1: The Log-Periodic receiving antenna.

The testbed is a broadband (Max.100 MHz) channel sounder developed at Universidad Politécnica de Madrid (UPM) [8]. Table 1 demonstrates the main features of the channel sounder. During the testing, the signal of the transmitter is modulated with a 47 nanoseconds narrow pulse and transmitted. The receiver has a dual conversion system with a final logarithmic amplifier that demodulate the pulse. Then the demodulated signal is acquired using a digital oscilloscope, which permits to acquire the time delay profile of the channel on real time with high precision.

The layout of the measurement environment is briefly illustrated in Fig.2, which include the size of the station and the cross section of the tunnel. The length of the train and tunnel also can be found in Fig.2. During the tests, the transmitter is always installed on the platform close to the train, the receiver placed in parallel with the transmitter in Test 1 and installed on the window of the train in Test 2. Both Test 1 and Test 2 are performed at two frequencies: 2450 MHz and 1000 MHz, respectively. The main objective in the tests is to get the Power Delay Profiles (PDPs), which gives the

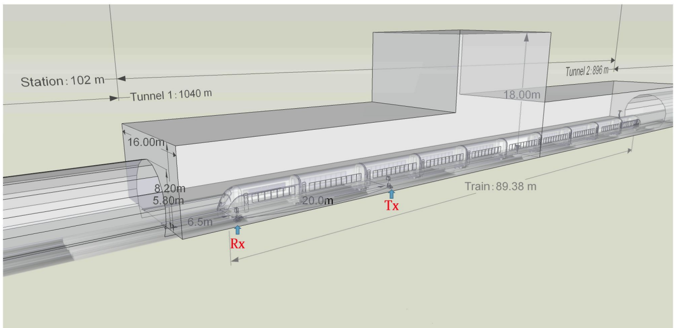


Fig. 2: 3D scenarios for testing the effect from the train: transmitter and receiver are located in the train station.

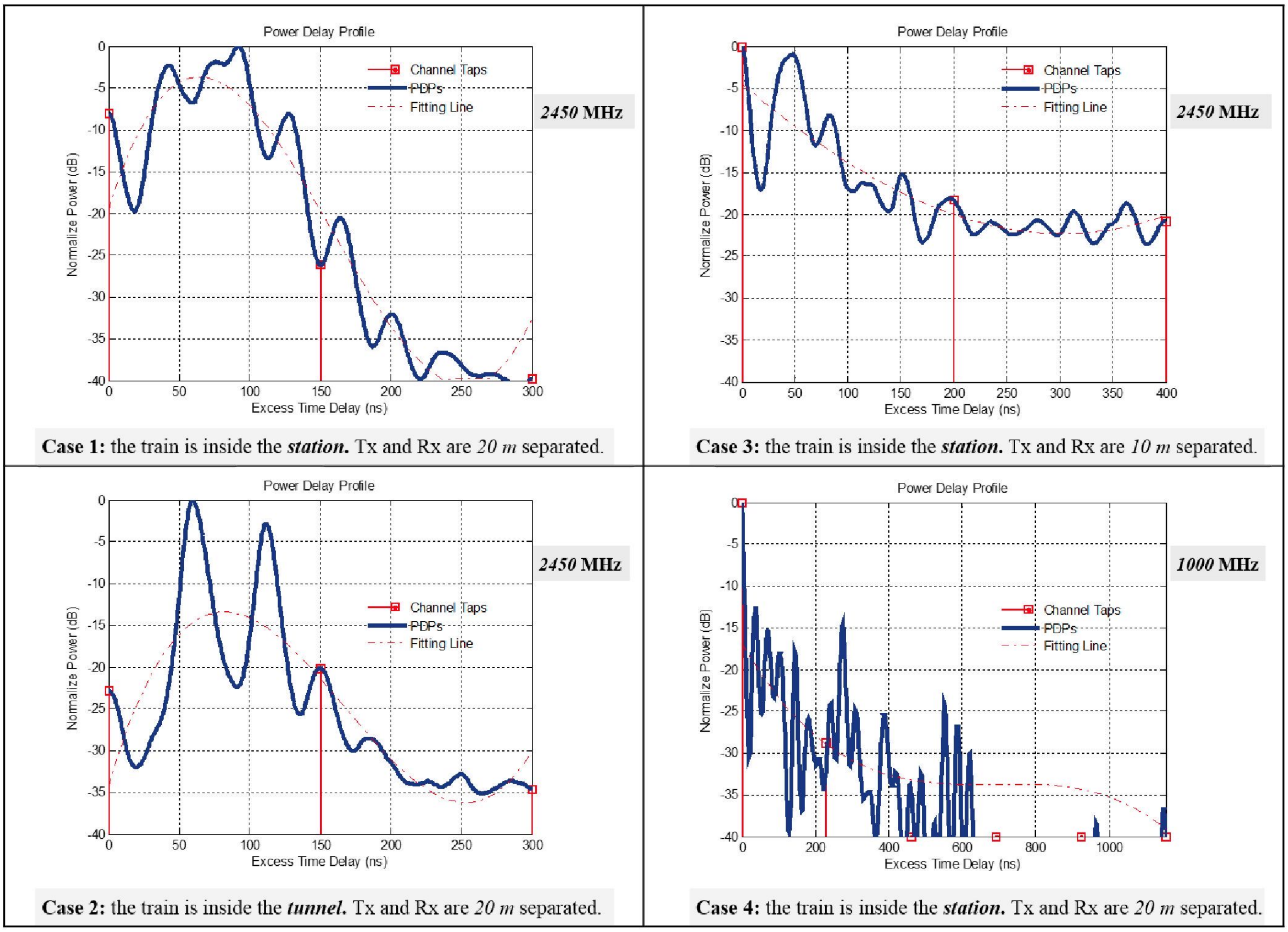
amplitude of the received signal in every instance through a multipath channel as a function of time delay. The time delay spread can clearly determine the extent of multi-path effects on a radio communication channel. Therefore, PDPs is widely used to characterize the wireless channel. Base on the PDPs curve, certain channel parameters can be extracted: such as the earliest significant multipath components, which is typically judged to be the line of sight (LOS) path; the root mean square (RMS) delay spread which in turn is useful to determine the number of channel taps, one of the key parameters needed for signal propagation model to expect an equivalent wireless channel without Inter Symbol Interference (ISI) [9],[10].

III. Measurements and results analysis

A. Test 1: Propagation in subway station and the effect of train passing.

In the anticipation of the test plan, the first objective is considering the radio signal propagation inside a subway station under two effects: effect from the spatial structure and materials of the subway station, and when it passing close to the transmitter and receiver, the effect from the train's body. To accomplish these, we fix the RF equipments on the subway platform, and place the RF receiver close to the entrance of the station. Then a set of scenarios are set up to compare the effect when the train stop in different position in the train station and tunnel. For instance, The Fig.2 shows the 3D scenarios when the train is located in the middle of the station and stopped in the tunnel, and transmitter and receiver are separated with 20 m.

The main idea of Test 1 is to analyse the impact of the walls and size of the station and the effect of the train arriving to it. For this reason we make measurements with different positions of the transmitter and the train and at different frequencies. Through some simple statistics and normalization processing, the PDPs can be extracted from the digital oscilloscope. In Fig.3, four different broadband testing cases are chosen to compare and analyse the behavior of radio signals, and assess the impact of various main factors on the broadband signal transmission in subway station as a multipath Non-Line-of-Sight (NLOS) channel. Moreover, Table II provide the key statistical parameters of Fig.3 for further channel modeling.



Case 1: the train is inside the ***station.*** Tx and Rx are *20 m* separated.

Case 3: the train is inside the ***station.*** Tx and Rx are *10 m* separated.

Case 2: the train is inside the ***tunnel.*** Tx and Rx are *20 m* separated.

Case 4: the train is inside the ***station.*** Tx and Rx are *20 m* separated.

Fig. 3: Power Delay profiles at two frequencies and in different conditions.

Case	Frequency	Train's Location	Separation	Mean Power	Std. deviation	RMS-DS	Channel taps
Case 1	2450 MHz	Station	20 m	-20.9795 dB	14.1450 dB	73.4333 ns	3
Case 2	2450 MHz	Tunnel	20 m	-24.9591 dB	9.7949 dB	89.2842 ns	3
Case 3	2450 MHz	Station	10 m	-17.4352 dB	6.1202 dB	103.8821 ns	3
Case 4	1000 MHz	Station	20 m	-28.9054 dB	7.4600 dB	230.4453 ns	6

TABLE II: Statistical parameters of Fig.3.

The PDPs curves in Fig.3 expound the abundant propagation information of the wireless channel. For instance, the first component that arrived earliest to the receiver, can be identified as the direct ray to the back lobe of the receiving antenna, and as the reference time delay in all cases. Then the effect from the train body can be easily found: through the comparison between Case 1, Case 2 and Case 3 that RF equipments work at the same frequency, there is a clear contribution in the time delay around 70 ns in Case 1, 70 ns time delay means the radio wave experienced a reflection path with additional length approximately equal to 24 meters, which can be presumed to the reflection path between the train body and antennas. Then the PDPs curve in Case 2 confirms our speculation, because the contribution around 70 ns is absence when the train is not inside the station. The contribution around 70 ns changes with the position of the passing train, but the delay spread duration do not increase or decrease. However, the fitting lines in Case 1 and Case 2 are quit similar, and the mean power and RMS delay spread are very close as well with the same number of channel taps. So we can conclude that the influence of the train body on the delay spread in as small as expected.

Another interesting comparison between Case 1 and Case 4 is worth to mention. It shows that the RMS delay spread in a subway station with train is clearly different between 2450 MHz and 1000 MHz. Maximum delay at 1000 MHz (case 4) is 1200 ns for -36 dB loss, while in Case 2 at 2450 MHz maximum delay is around 240 ns. This is because propagation loss in the free space at 1000 MHz is much smaller than at 2450 MHz. Thus, each multiple path experiences smaller propagation loss at lower frequency. Therefore, more multi-path components are retained and finally received at 1000 MHz. From these results we can say that propagation of broadband communications in stations with hard walls and a lot of steel panels is better at 2450 MHz, because a smaller RMS delay spread yields fewer channel taps, which means a wireless channel with higher capacity.

Additionally, we move the Tx and Rx to be closer in Case 3. Then the only difference is that there is a clear and strong direct ray, but multi-path components are not as strong as in the case 1 when the Tx and Rx are 20 m away. This is because that when the distance between the Tx and the Rx is only 10 m, the incidence angles of the reflections in the region between Tx and Rx decrease, thus, the strength of the reflections decreases as well.

B. Test 2: The tunnel effect testing and analysis.

The aim for the second group testing is checking the effect on the signal propagation when the train passing from the station to the tunnel. On this case we expect an important reduction of multipath and therefore a very small delay spread inside the tunnels. Therefore, we arrange the R&S HL025 Log-Periodic antenna works as receiving antenna. It is adsorbed on the windshield of the last car to test the effect from the tunnel at different positions. The transmitting antenna system is located in the middle of the platform. Furthermore, the initial position of the train is where the train's tail is close to the transmitting antenna. Then the train is gradually stopped at the position away from the transmitter and heading for the tunnel. This leaving process continues until the train has entered a very dark tunnel and very far away from the station about 1000 m. The 3D scenarios of the testbed and environment is revealed by Fig.4.

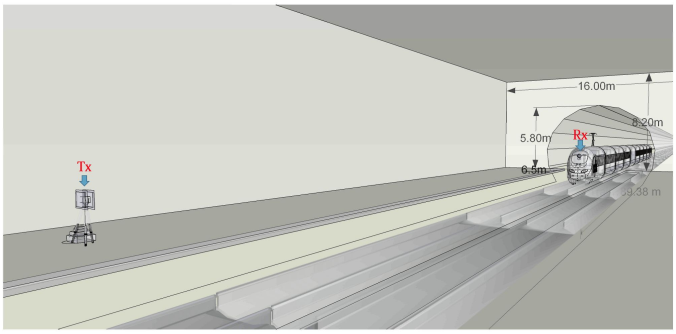


Fig. 4: 3D scenarios for testing the effect from the tunnel: transmitter is located in the middle of station, and the receiver is adsorbed on the tail of the train.

After the similar data post-processing, several PDPs are collected and normalized from the testing results at two frequencies and represented by two 3D graphs that illustrated in Fig.5. The results explain how the power of received signal from multipath components decreasing, when the train passes from the subway station to the tunnel and farther away from

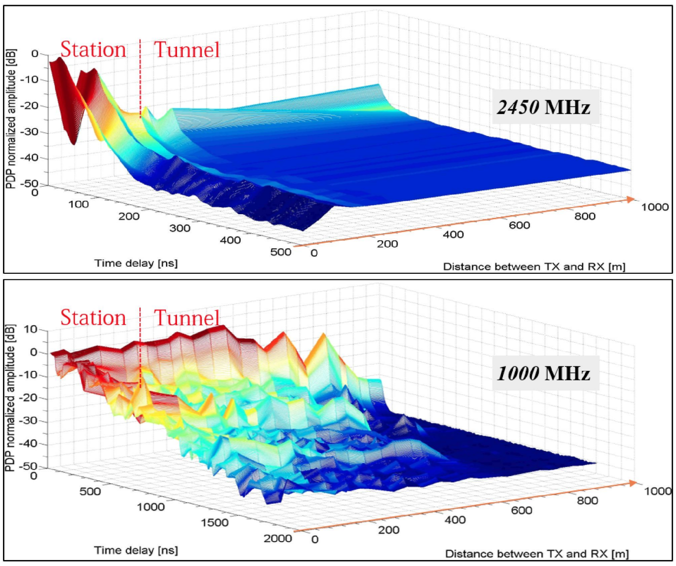


Fig. 5: The second group testing results.

the transmitter. We can see at 2450 MHz, there is almost only one considerable ray received by the train, which correspond to the first arriving path that is actually the first-order reflection. The rest of the multipath effects are suppressed by the effect of the tunnel. By comparing the two 3D graphs, we can say the effect from tunnel is more significant at 2450 MHz, but it is also remarkable at 1000 MHz. In this case the delay profile of the station is still present but less attenuated by the tunnel, which is consistent with the waveguide theory. Also the multipath components are also disappeared after the train is more than 600 meters away from the station entrance.

These phenomenas we observed provides important information about the optimum position to deploy base stations in railway environment: the optimum position is that inside the tunnel and close to entrance of the station. Because the multipath components in the station will be highly reduced with this configuration, and the radio communication system keeps a relatively good signal coverage.

IV. Conclusions

In this paper, a set of broadband communication measurements in subway station and tunnels are described and analysed. The measurements results collected by a proprietary channel sounder are very relevant and reveal some important appearances of the subway channel. For instance, the small effect of the train in the subway station; higher propagation loss in the station and faster reduction of the delay spread inside tunnel on higher frequency. Base on these results, we can summarize that the ideal location for the Base Transceiver Station is inside the tunnel and close to the entrance of the subway station for network planning. And 2.4 GHz or 5.7 GHz is more suitable than 1000 MHz for subway communication system. Moreover, our configurations during the measurements such as antenna location in train and infrastructure, transmission power, optimal frequency band and available bandwidth are all key parameters for the future deployment of 4G systems in complex railway environments.

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